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TWO ASPECTS OF EARTH PENETRATION: MEASUREMENT OF RESISTANCE TO BURIAL AND THEORETICAL PREDICTION OF PENETRATION IN STRATIFORM SOIL

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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ABSTRACT: (U) Within the scope of the work conducted in the discipline of controlled penetration in soils, techniques are outlined and suggested which should help the investigator estimate the resistance to penetration (soil factor) at a location in a few minutes using portable equipment. Included is a compilation of soil penetration data from various locations. Additional work has also been completed which enables the researcher to theoretically predict burial depths of impacting vehicles in stratiform soil or earth.

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TWO ASPECTS OF EARTH PENETRATION: MEASUREMENT OF RESISTANCE TO BURIAL AND THEORETICAL PREDICTION OF PENETRATION IN STRATIFORM SOIL

This report presents the results of the soil investigation and prediction of soil penetration phases of the work on the Advanced Destructor during Fiscal Year 1969. These studies were conducted within the Independent Exploratory Development (IED) Program at the Naval Ordnance Laboratory, White Oak, Maryland under MATTASK MAT-03L 000/ZF17 312 001 PA 065.

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Captain, USN
Commander

C C Vogt for

C. F. BOWERSETT
By direction

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TABLES

ILLULTRATIONS

Chapter 1

PROBLEM DEFINITION AND BACKGROUND

INTRODUCTION

1-1. (U) In recent years, there has been increasing interest in earth-penetrating phenomena. Notable in this field is the work of the Sandia Laboratories, Albuquerque, New Mexico. The prediction of the depth of penetration of vehicles and the subsequent control of this depth has many applications, both civilian and military. Such information would be useful in:

a. making rapid geological surveys
b. determining the effectiveness of buried explosive charges
c. deployment of certain land/shallow water ordnance

1-2. (U) At a particular test site, to accurately predict penetration depth, it is necessary to accurately forecast a parameter known as the Soil Factor. The Soil Factor is a measure of the resistance to penetration and, naturally, may vary from location to location. In lieu of conducting a full-scale penetration test, in which all parameters except the Soil Factor are well known, it would be helpful to be able to predict the Soil Factor by completing a simple test using portable equipment.

1-3. (U) The penetration test results reported thus far by Sandia were obtained using right circular cylindrical vehicles with various nose configurations. But, when "terra-brakes" (appendages) are introduced to retard penetration, an additional technique may be employed to adapt the present equations to this application. Likewise, additional methods are necessary when such vehicles penetrate through strata of soils.

BACKGROUND

1-4. (U) Sandia Laboratories, Albuquerque, New Mexico, is currently involved in investigating the mechanisms of earth penetration. Their research should culminate in an analytically determined equation. In the meanwhile, C. W. Young of Sandia has published in reference (a) empirical penetration equations based on a rather

comprehensive test program of full-scale vehicles penetrating a variety of targets (ref. (a)). The resulting equations are: For velocities less than 200 feet per second ($V < 200$ ft/sec)

$$D = .53\ S\ N\left[\frac{W}{A}\right]^{\frac{1}{2}} \ln(1+2V^2\ 10^{-5}) \qquad (1)$$

and for velocities greater than or equal to 200 feet per second ($V \geq 200$ ft/sec)

$$D = .0031\ S\ N\left[\frac{W}{A}\right]^{\frac{1}{2}} (V-100) \qquad (2)$$

where:

D ~ Total depth of penetration, measured along the path, ft
S ~ Soil Factor, dependent only upon soil properties
N ~ Nose Factor, nose performance coefficient
W ~ Weight of projectile, lbs
A ~ Frontal area of projectile, in^2
V ~ Impact velocity, ft/sec

The nose-performance coefficient is a function of the geometry of the nose. For the convenience of the reader, these nose factors are presented for various shapes in Appendix A.

1-5. (U) The Soil Factor, S, is a function of resistance to penetration of an object. Sandia reports refer to it as an "index of penetrability". If a previous full-scale test has been conducted in the very immediate area, the results of that test may be used to determine a soil constant (using formula (1) or (2)) which may be used for additional drops. It would be convenient and helpful to be able to specify the soil factor after conducting just a simple test using portable equipment. Some typical values of S are included in Appendix B.

1-6. (U) To investigate the behavior of a controlled-penetration vehicle, a technique must be developed to adapt equations (1) and (2). These equations are for cylindrical bodies (described in the introduction). A controlled-penetration vehicle has "terra-brakes", appendages that increase the frontal (cross-section) area immensely; they act like earth-drag-brakes. Figure 1-1 shows such a prototype used in NOL's investigation. These vehicles are designated by the code ADST.

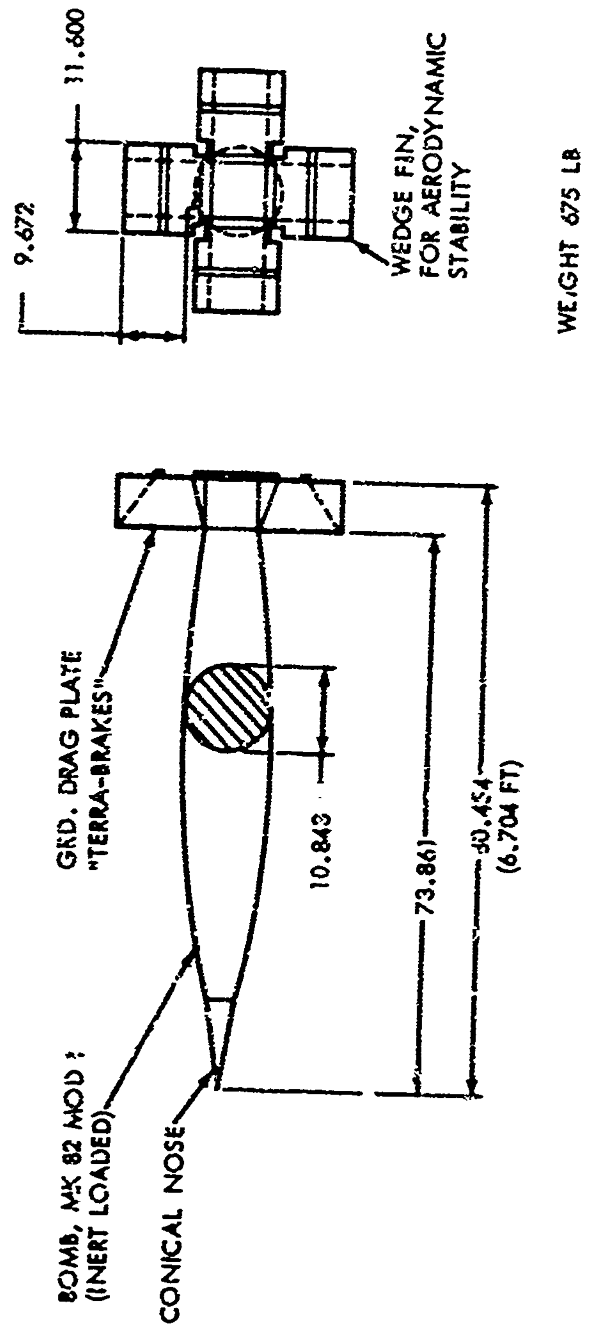


FIG. 1-1 CONTROLLED-PENETRATION VEHICLE (ADST)

Chapter 2

SOIL INVESTIGATIONS

DEVICES THAT MEASURE RESISTANCE TO PENETRATION

2-1. (U) An accurate forecast of the resistance to penetration at a test site is essential in predicting expected depth of burial of test vehicles. There are available two means of directly measuring this "resistance", the Standard Penetration Tester (SPT) and the Dynamic Cone Penetrometer (DCP). Both work on the same principle, essentially recording the number of blows from a falling weight necessary to drive a rod through a given distance in the soil (called the Blow Count). The difference between them is found in their bulkiness and availability. The SPT is a standard piece of equipment found world-wide wherever heavy construction is in evidence. The results of a SPT may even be required in the local building codes. This equipment and its associated drilling accessories weigh several hundred pounds and are truck mounted. The DCP is very portable weighing only about 30 lbs and is hand carried and hand operated. It is a Sandia development (in its basic form) and has limited distribution.

2-2. (U) a. STANDARD PENETRATION TESTER (SPT) - The Standard Penetration Tester consists of the following essential components (see Fig. 2-1):

i. a hammer-weight (140 lb)
ii. the necessary length of drill rod
iii. a split spoon for recovering samples

The spoon is attached to the drill rods and lowered to the bottom of a drilled hole that has been cleared of loose material by an auger. The spoon is seated in the bottom of the hole with a few blows of the hammer-weight (usually about 6 inches). The test consists of counting the number of blows of the drop weight required to drive the sampling spoon into the soil for a distance of one foot (sometimes recorded in one-half foot intervals). The weight is 140 lb and the height of the fall is 30 inches. The spoon has an OD of 2 inches and an ID of 1 3/8 inches. A detailed description of the procedure is contained in reference (b), as ASTM Test Designation D1586-64 T. Additional information may be obtained from reference (c).

2-3. (U) There is some correlation between the Soil Factor in the Sandia terra-dynamics work (ref. (a)) and the Blow Count of an SPT. Figure 2-2 is based on data found in reference (a). The data represents more than one class of soils.

2-4. (U) b. DYNAMIC CONE PENETROMETER (DCP) - The Dynamic Cone Penetrometer is a simple hand held soil penetrometer similar in many respects to the SPT, "a scaled down version". It is a development of the Sandia Laboratories, Albuquerque, New Mexico, and reported in reference (d). The major components as depicted in Figure 2-3 are:

i. a 12 lb weight
ii. necessary one foot sections of ½ inch rod
iii. conical nose piece

2-5. (U) The operational procedures of the DCP and SPT are different. The DCP starts at the surface and is driven into soil. The test is stopped only to note the blow count each foot and/or to join additional sections of rod for further penetration. This differs from the SPT which is placed in a predrilled hole and must be extracted after each foot of testing to remove the soil sample from the spoon.

2-6. (U) The NOL investigators were able to extend the use of the DCP from a recommended 5 ft to a 10 ft depth without noticing any unsatisfactory performance, provided that no more than 4 feet of sections are above the ground at any time. The use of the DCP is a one or two man operation, and requires about five minutes to obtain a set of readings at one site hole.

SOIL FACTOR DETERMINATION FROM DCP TESTING

2-7. (U) In the process of evaluating prospective drop test sites for the controlled-penetration vehicle, a large sampling of DCP data was collected. This data covers a variety of natural earth topography: sand dunes, marshes, rice paddies, fields, etc. The locations are in Southeast Asia and the eastern section of the USA. This information is presented in Appendix C.

2-8. (U) The one interesting phenomenon, uncovered during the survey of test sites, concerned marshes. It would seem reasonable, at first thought, that wet soil is soft land. This is true. Yet, what keeps the water from draining off? One answer is the harder bottom found underneath each marsh visited. The marsh may be like a bog or quagmire for three to eight feet, but then it hardens up promptly and forms a denser pan to hold the water.

2-9. (U) In a recent test at the Naval Ordnance Laboratory Test Facility (NOLTF), Solomons, Maryland, the opportunity arose to conduct SPT and DCP tests side-by-side. Some correlation does exist between the "Blow Count" of the Dynamic Cone Penetrometer (DCP) and the "Blow Count" of the Standard Penetration Tester (SPT). These results are presented in Figure 2-4. Three least square straight line fits are also sketched in. The equations of these lines are:

1. all-points: (SPT) = .539+.506 (DCP) (3)
2. high-points: (SPT) = 4.63+.377 (DCP) (4)
3. low-points: (SPT) = 2.13+.265 (DCP) (5)

The Soil Factors, obtained from Figure 2-2, have also been included along the ordinate axis. Thus, correlation between the DCP testing in this field and the Soil Factor can be demonstrated.

2-10. (U) Figure 2-4 has been used in obtaining Soil Factors for theoretically predicting penetration depths. These predicted depths agree closely with actual data in tests. This will be covered fully in Chapter 3.

2-11. (U) It is interesting to note that the slope of equation (5) is about what is predicted from theoretical considerations for the ratio of penetration of the DCP to SPT. If we let subscript D pertain to the DCP and S to the SPT and make the ratio D_D/D_S, one obtains:

a. using conservation of energy

$$\frac{D_D}{D_S} = \left(\frac{N_D}{N_S}\right) \frac{\left[\frac{W_D}{A_D}\right]^{\frac{1}{2}} \frac{w_D}{W_D}}{\left[\frac{W_S}{A_S}\right]^{\frac{1}{2}} \frac{w_S}{W_S}} \left(\frac{h_D}{h_S}\right) . \tag{6}$$

b. considering the system from the point of view of an inelastic collision

$$\frac{D_D}{D_S} = \left(\frac{N_D}{N_S}\right) \frac{\left[\frac{W_D}{A_D}\right]^{\frac{1}{2}} \left[\frac{w_D}{W_D}\right]^{2}}{\left[\frac{W_S}{A_S}\right]^{\frac{1}{2}} \left[\frac{w_S}{W_S}\right]^{2}} \left(\frac{h_D}{h_S}\right) . \tag{7}$$

where: w ~ weight of drop weight
W ~ weight of total system
h ~ height of fall of weight

Using values for typical configurations of each penetrometer,

$$\frac{N_D}{N_S} = 1 \qquad \frac{h_D}{h_S} = .4 \qquad A_D = .442 \text{ in}^2$$

$$A_S = 1.65 \text{ in}^2$$

$$w_S = 140 \text{ lbs} \qquad w_D = 12.5 \text{ lbs}$$

$$W_S = 218 \text{ lbs} \qquad W_D = 17.5 \text{ lbs}$$

$$\frac{w_S}{W_S} = .642 \qquad \frac{w_D}{W_D} = .714$$

We obtain:

from equation (6) $\frac{D_D}{D_S} = .24$

and from equation (7) $\frac{D_D}{D_S} = .27$

UNDERWATER MOD OF DCP

2-12. (U) Since the Laboratory is interested in predicting the degree of burial of a vehicle when it impacts on the bottom of a body of water, the DCP has been modified for underwater use. The instrument would be operated by divers. The scheme is presented in Figure 2-5.

2-13. (U) The height of fall (of the drop weight) has been increased such that the maximum force output when the weight strikes the bumper is the same underwater as experienced in air.* This increase in height "compensates" for the water's viscous drag acting on the drop weight.

2-14. (U) Typical results of testing the DCP in air and water are (in pounds):

	HEIGHT OF FALL	
	1.0 ft	1 ft 2 in
In Air	200-208	---
In Water	180-185	200-208

The additional height needed is 2 inches.

*This should result in some correspondence between underwater testing and dry testing.

2-15. (U) This modified DCP has not been employed in any actual underwater tests yet, but the authors are confident about its success.

FUTURE WORK

2-16. (U) The correspondence between the Soil Factor and the SPT blow count for a variety of soil types and the success with our limited testing indicates that additional testing may yield a correlation between the DCP and the Soil Factor for dissimilar soils over a spectrum of soil hardnesses. The authors realize that this is just a beginning, but the results seem to indicate that further testing at harder sites and in different soils will permit refinement of the present results and preparation of a mathematical expression for the relationship between DCP blow count and Soil Factor.

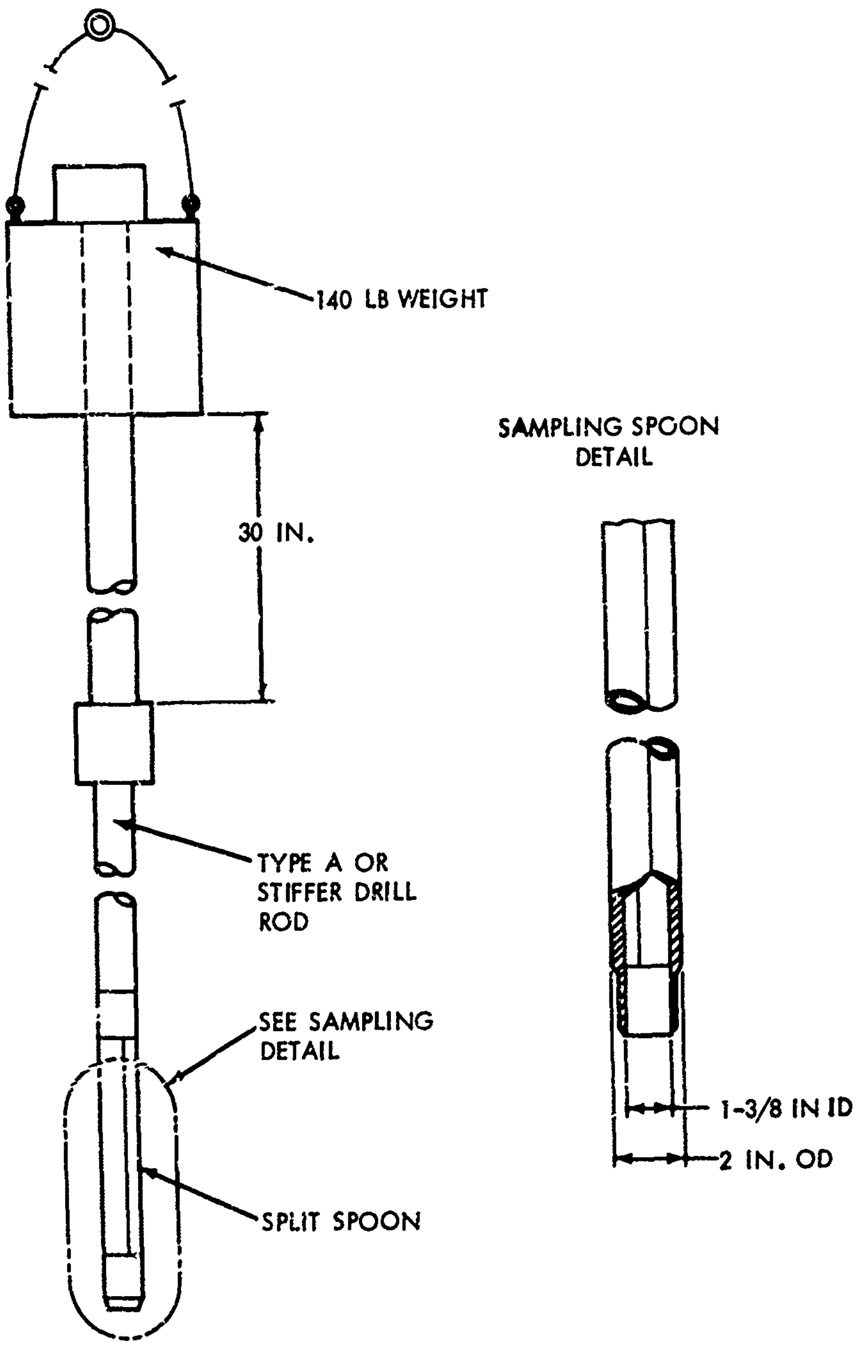


FIG. 2-1 STANDARD PENETRATION TESTER

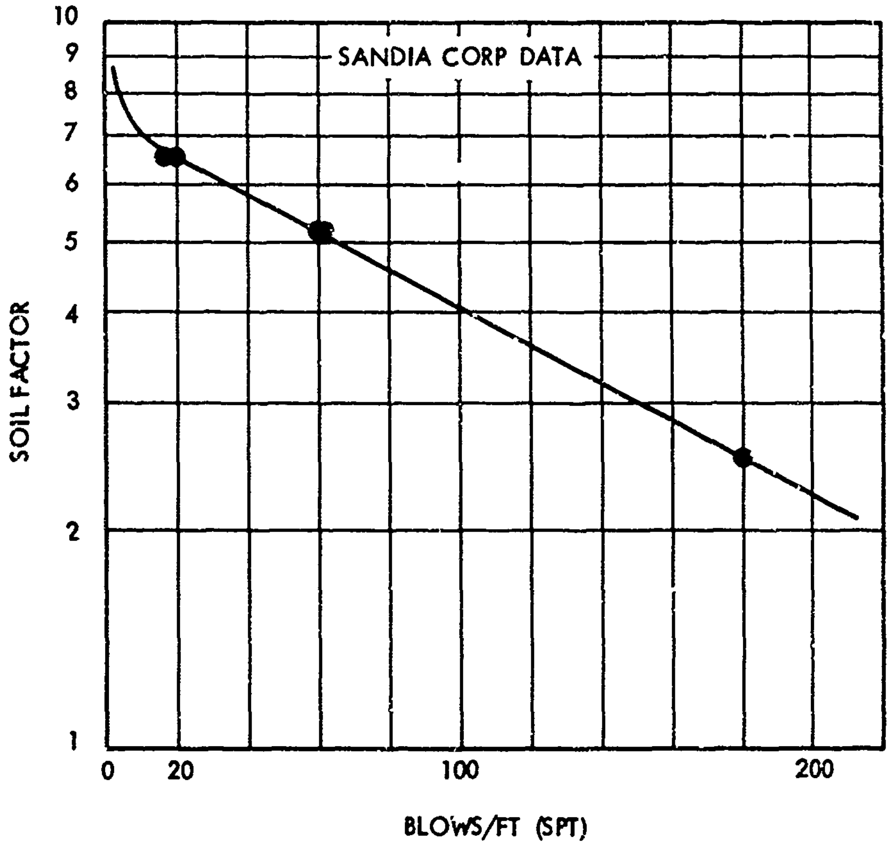


FIG. 2-2 SOIL FACTOR VS SPT

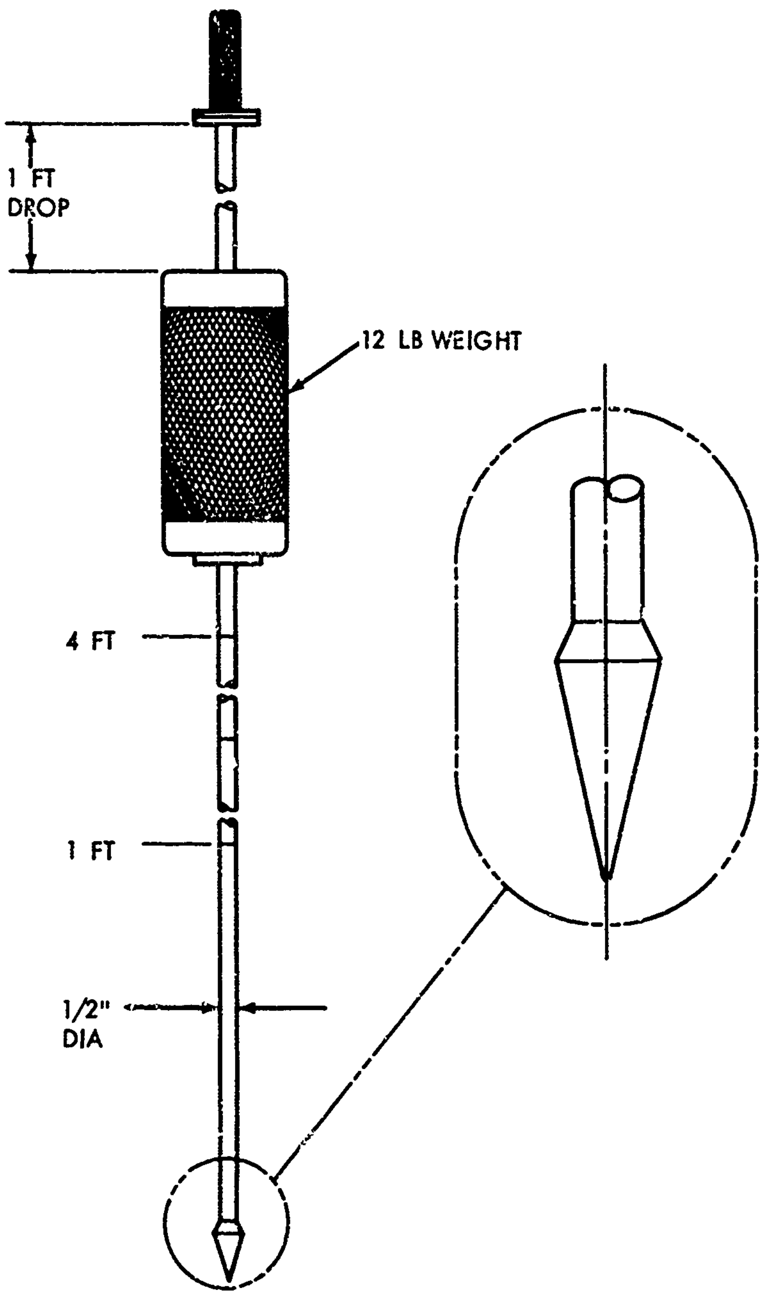


FIG. 2-3 DYNAMIC CONE PENETROMETER (DCP)

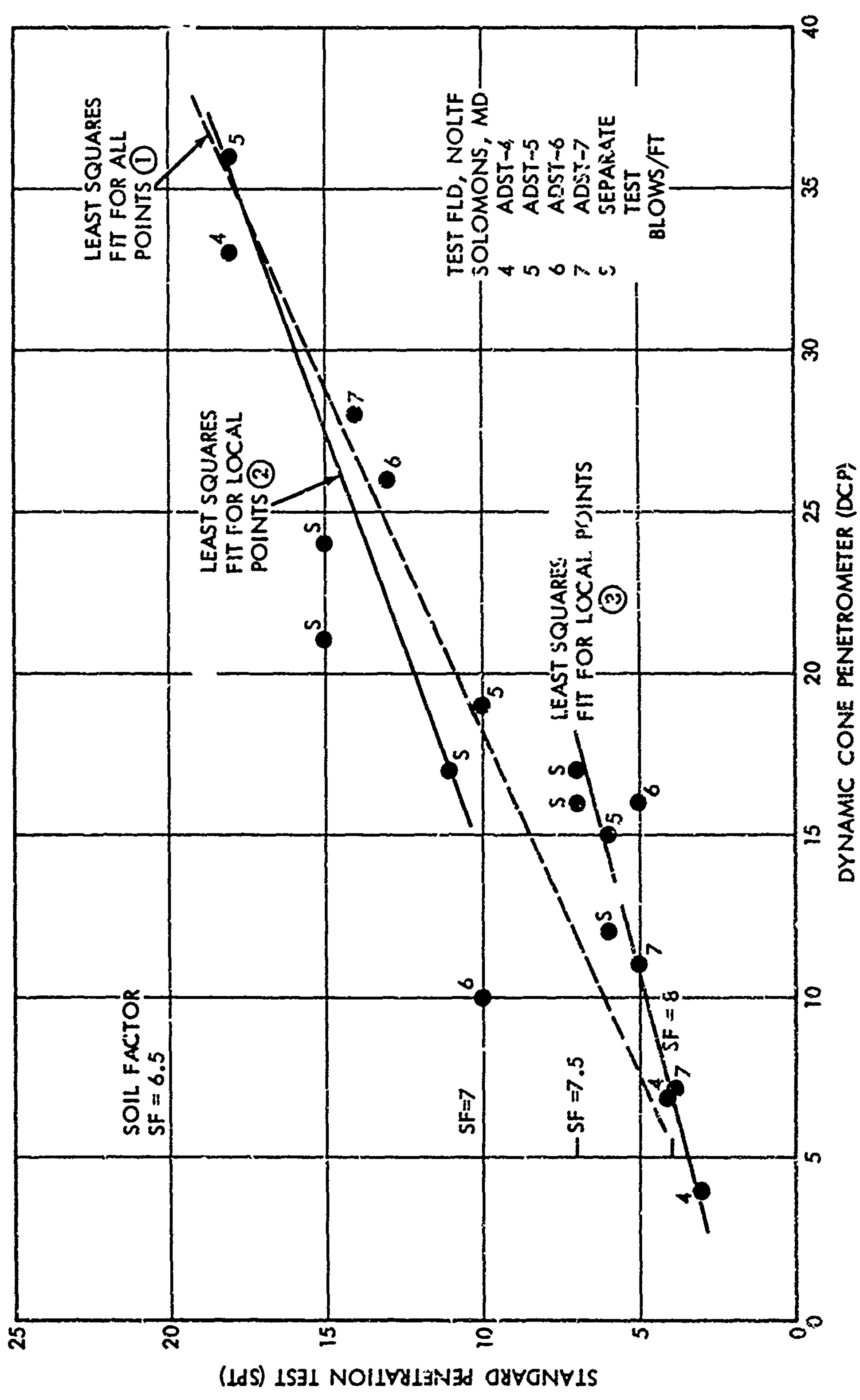


FIG. 2-4 DCP VS SPT COMPARISON

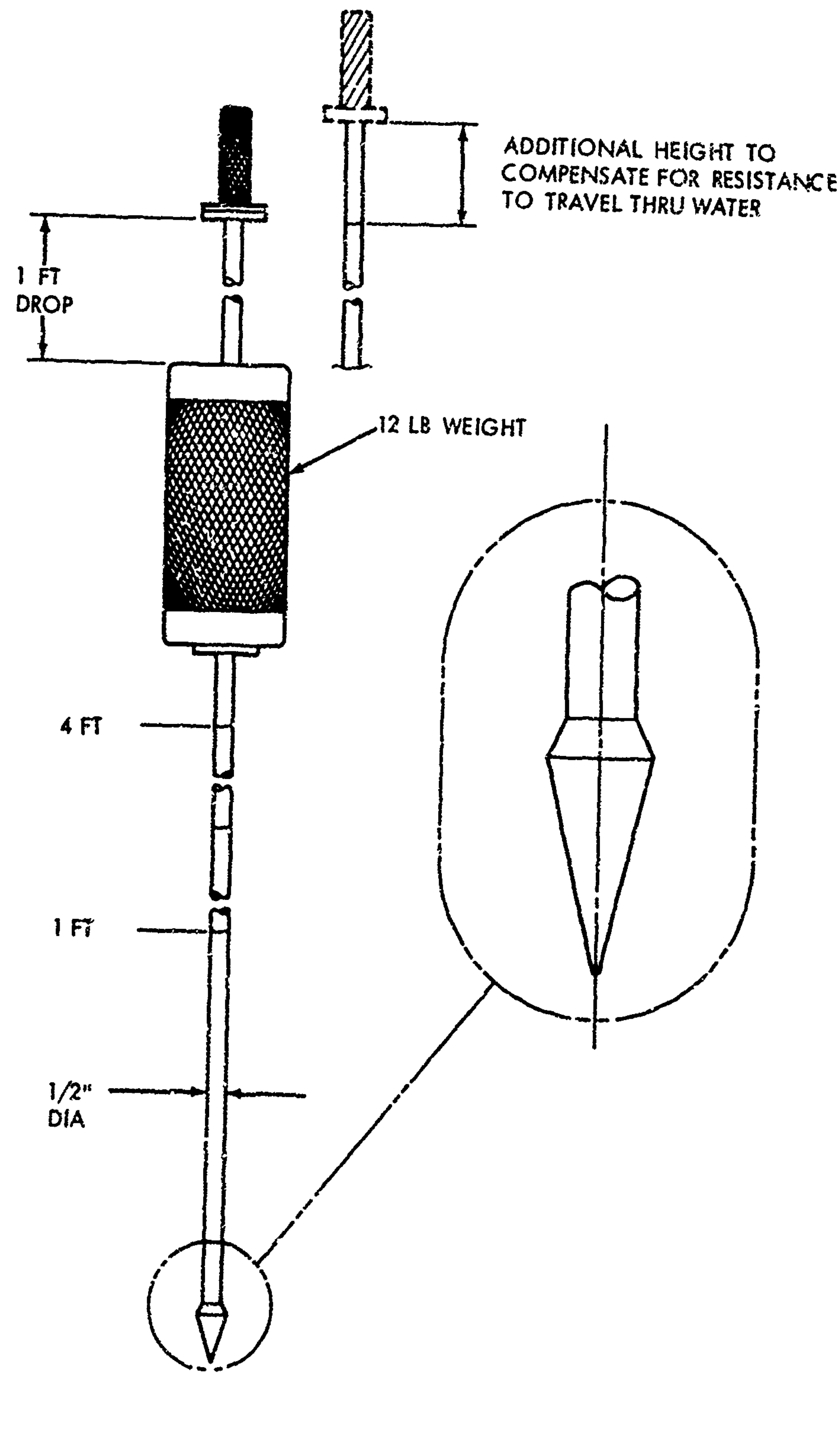


FIG. 2-5 DYNAMIC CONE PENETROMETER (DCP) UNDERWATER CONFIGURATION

Chapter 3

CONTROLLED PENETRATION INVESTIGATIONS

INTRODUCTION

3-1. (U) The NOL investigation of ground penetrating vehicles is unique, in that the Laboratory is interested in minimizing the penetration of the vehicle beyond its submerged depth. A particular design of a controlled-penetration vehicle is shown in Figure 1-1. It has a conical nose ($1/d^{*} = 3$) and drag plates (called "terra-brakes") attached to the tail. The conical nose allows "efficient" ground penetration to the submerged depth. At this point, the "terra-brakes" greatly increase the drag on the vehicle and retard its further travel.

3-2. (U) To design such a vehicle, the designer must determine parameters such as "terra-brake" surface area, nose shape, etc. It would be helpful to know how these parameters affect the total performance of the vehicle. The penetration equations, developed by the Sandia Laboratory, (see ref. (a)) are the key for developing such an analytical tool.

CONTROLLED-PENETRATION VEHICLE ANALYSIS

3-3. (U) For drops into a homogeneous soil, (constant soil factor) the performance of the controlled-penetration vehicle must be analyzed in two parts: before and after impact of the "terra-brakes". In part one the controlled penetration vehicle behaves like a projectile with an "efficient" nose, and no "terra-brakes" (see Fig. 3-1). Such a vehicle would penetrate to a depth D, calculated using the Sandia equations. The velocity, V2, at the point of full penetration (the point of impact of the "terra-brakes") can be calculated as follows:

$$V2 = V1 \sqrt{1 - \frac{T(1)}{D}} \tag{8}$$

* Ratio of nose length to major diameter.

where: V1 = impact velocity of nose
T(1) = length of projectile, to the "terra-brakes"

3-4. (U) A parameter defined as the "equivalent area", A_E, must be calculated for part two of the analysis. Consider a hypothetical projectile which has a flat nose. The area of this flat-nosed projectile must be such that it will penetrate to the same depth as the "efficient-nosed" vehicle, all other parameters remaining constant. Mathematically, this area is:

$$A_E = A \left(\frac{N_2}{N_1}\right)^2 \tag{9}$$

where:

A = cross-sectional area of controlled-penetration vehicle
N_1 - shape factor for the "efficient" nose (1.32 for a 3 to 1 conical nose)
N_2 - shape factor for the flat nose

3-5. (U) When the "terra-brakes" impact the surface, several parameters change, and part two of the analysis begins. At this point, the vehicle is considered to be a new, flat-nosed projectile, traveling at a velocity, V2. The frontal area, E, of the projectile is the "equivalent area", A_E, added to the "terra-brake" area, X.

$$E = A_E + X \tag{10}$$

With these parameters, the penetration, D', of the flat-nosed vehicle beyond its submerged depth is calculated. This penetration is considered to be the same as that of the controlled-penetration vehicle.

PENETRATION INTO STRATIFORM SOIL

3-6. (U) Field tests have shown that the soil hardness varies at different depths in the ground. In this situation, it is necessary to consider the changing soil characteristics to more accurately analyze the performance of the controlled-penetration vehicle. When the soil factor changes considerably, as in marshes, meaningful data could not be obtained using the analysis for homogeneous soils.

3-7. (U) The analysis of the performance of the controlled-penetration vehicle in stratiform soil is long and tedious, especially when numerous layers exist. Fortunately, it is possible to program the analysis and have the computer perform the computations. Such a program, written in the BASIC language, is presented in Appendix D. It is accompanied by a flow chart to help familiarize the reader with

the logic and operations of the program. It calculates the penetration of the controlled-penetration vehicle with "terra-brakes" and for comparison, without "terra-brakes".

ANALYSIS OF PENETRATION INTO STRATIFORM SOIL

3-8. (U) The analysis of penetration into stratiform soil must be divided into steps, which will be called events. An event will occur when the nose or "terra-brakes" encounter a new layer. The event number will be indicated by the index K.

3-9. (U) Event one is the nose hitting layer one. The penetration, D(1), is calculated, using the appropriate Sandia equation and assuming that no "terra-brakes" are attached to the projectile (see Fig. 3-2). This datum is needed to calculate the velocity, V(2), when event two occurs. This velocity is calculated, using equation (8), where T(1) is replaced by the distance between events one and two.

3-10. (U) Event two is either the nose encountering layer two, or the "terra-brakes" impacting the ground. Since the computer "knows" the layer thicknesses and the dimensions of the vehicle, it can determine what event two, and subsequent events will be. If event two is the nose encountering layer two as shown in Figure 3-2, the computer calculates D(2), the penetration of the vehicle beyond layer one. It uses the velocity, V(2), just calculated and the Soil Factor, S(2), of layer two for this calculation.

3-11. (U) When the "terra-brakes" impact the ground, as occurs in event three of Figure 3-2, the effective nose shape of the entire vehicle, and the frontal area suddenly change. A parameter defined as the "equivalent area" must be calculated to define this new frontal area as discussed previously. The "equivalent area" for the analysis in stratiform soil can be described by considering two hypothetical projectiles. The first has a nose and cross-sectional area the same as the controlled-penetration vehicle. It is considered to act in the same type of soil, S(I), being penetrated by the nose of the controlled-penetration vehicle at the event being considered. The second has a flat nose of area, A_E, and acts in the same type of soil, S(J), as the "terra-brakes". The area, A_E, defined as the "equivalent area", is such that the vehicles will penetrate the same distance, all other parameters being the same. Mathematically:

$$A_E = A\left[\frac{N_2}{N_1}\right]^2\left[\frac{S(J)}{S(I)}\right]^2 \qquad (11)$$

where

S(J) = soil factor of layer encountered by "terra-brakes"

S(I) = soil factor of layer encountered by the nose

3-12. (U) The "equivalent area", A_E, added to the "terra-brake" area, X, constitutes the total frontal area of the flat-nosed configuration for event (3) (see equation (10)). Using the soil factor, S(1), for layer one, the penetration, D(3), of this configuration is calculated. The program determines the type of event (4), recalculates the "equivalent area" and velocity and uses this data to calculate D(4), the penetration of the nose beyond layer (3). This iteration process continues checking for the proper sequence of events until the projectile comes to rest between events.

3-13. (U) Information about the soil being penetrated is entered into the computer using statement 920. The format of this statement is:

920 DATA Z, S(1), M(1), S(2), M(2),....S(Z), M(Z).

M(Z), the thickness of the last layer, must be sufficiently large to insure that the projectile will not penetrate beyond that layer.

DISCUSSION OF RESULTS

3-14. (U) Two test drops into stratiform soil have been made with the controlled-penetration vehicle. The physical characteristics of these vehicles and the results of the tests are list[illegible] in Table 3-1. Theoretical values of penetration were calculated using the before mentioned program and are compared with the actual test results in this Table. These theoretical results fall within about 12 percent of the actual test results. Before any conclusions can be made with this data, two factors affecting the theoretical results must be discussed.

3-15. (U) As indicated in reference (a), the accuracy of the Sandia equations is "strongly" dependent upon the accuracy with which the soil factor is determined. In their testing program involving about 200 drops, they experienced an error in depth prediction exceeding 20 percent in 9 percent of the tests and exceeding 25 percent in less than 1.5 percent of the tests.

3-16. (U) A second factor affecting the predicted value of penetration is the number of layers which are considered in the analysis. Each time the program performs an iteration to consider a new layer, the value of penetration becomes inflated. This effect is demonstrated in Table 3-2. In run #1, one infinitely thick layer is considered

and the depth of penetration is calculated. In run #2, the soil factor does not change but the program recalculates the velocity of the projectile at four foot intervals and determines the penetrations from each of those points. The total penetration for run #2 is 4.9 inches greater than for run #1. For one foot intervals (run #3), the penetration is inflated by 7.6 inches over run #1.

3-17. (U) With these considerations in mind, the designer must use some discretion in preparing the data for this analysis. It is preferable where feasible to consider drops into a homogeneous soil. If the soil factor changes only slightly, the number of layers considered should be kept at a minimum, or an average value of soil factor should be used. For the two tests reported in Table 3-1, two layers were assumed to exist to theoretically determine the penetration of the ADST vehicle. The one foot thick layers were grouped such that the soil factor of each group of layers differed by about unity. If the change in soil factor would have been greater, more groups or layers would have been considered in the analysis. It is also important to note that the harder the soil, the more sensitive will be the penetration to a change in soil factor.

3-18. (U) Future field tests with the controlled penetration vehicle should allow for:

a. corrections to be made in the analysis to eliminate the problem of the predicted penetration becoming inflated after each iteration, and

b. the ability to more accurately determine the soil factor.

These two improvements would help to increase the accuracy with which the penetration of the controlled-penetration vehicle could be determined.

TABLE 3-1

CONTROLLED PENETRATION VEHICLE, TEST RESULTS

Physical Characteristics:

Nose Shape Factor, Nl	1.32 (conical nose, 1/d** =3)
Diameter (max), D	10.843 in
Length to "terra-brakes", T(l)	73.861 in, 6.155 ft
Length, to Tail	80.454 in, 6.704 ft
Area of "terra-brakes", X	272 in^2
Weight	675 lbs

**Ratio of nose length to major diameter

TABLE 3-1 (Cont'd)

TEST DATA:		ADST-6				ADST-7			
IMPACT VELOCITY		373 FT/SEC				350 FT/SEC			
DATA SOURCE		TEST		THEORETICAL		TEST		THEORETICAL	
		DCP	SF*	LAYER NO.	SF	DCP	SF*	LAYER NO.	SF
DEPTH INTO GROUND (FT)	0	15	7.5			6	8		
		9				6			
	1	5	8			7	8		
		7				10			
	2	8	8			12	7.5		
		13		1	7.8	18		1	7.5
	3	11	8			20	7		
		7				19			
	4	16	7.5			11	7.5		
		10				15			
	5	20	7.5			10	7.5		
		14				16			
	6	27	6.5			18	7		
		30				19			
	7	45	6.5			26	7		
		40		2	6.6	24			
	8	26	7			28	6.5	2	6.5
	9	28	6.5			36	6.5		
Pene. to Tail		42 in		47 in		47 in		42 in	

*Soil Factor as Estimated from Figure 2-4

TABLE 3-2

EFFECT OF THE NUMBER OF LAYERS ON THE THEORETICAL RESULTS
(FOR ADST VEHICLE)

Impact velocity of nose (ft/sec) = 350
Impact velocity of terra-brakes (ft/sec) = 297.377

RUN #1

Layer No.	Soil Factor	Thickness (ft)
1	8	100

Pene. To Tail, with terra-brakes (ft) = 3.64261
Pene. To Tail, W/O terra-brakes (ft) =15.4281

RUN #2

Layer No.	Soil Factor	Thickness (ft)
1	8	4
2	8	4
3	8	100

Pene. To Tail, with terra-brakes (ft) = 4.05454
Pene. To Tail, W/O terra-brakes (ft) = 17. 3956

RUN #3

Layer No.	Soil Factor	Thickness (ft)
1	8	1
2	8	1
3	8	1
4	8	1
5	8	1
6	8	1
7	8	1
8	8	1
9	8	1
10	8	1
11	8	1
12	8	100

Pene. To Tail, with terra-brakes (ft)= 4.27103
Pene. To Tail, W/O terra-brakes (ft) = 18.1301

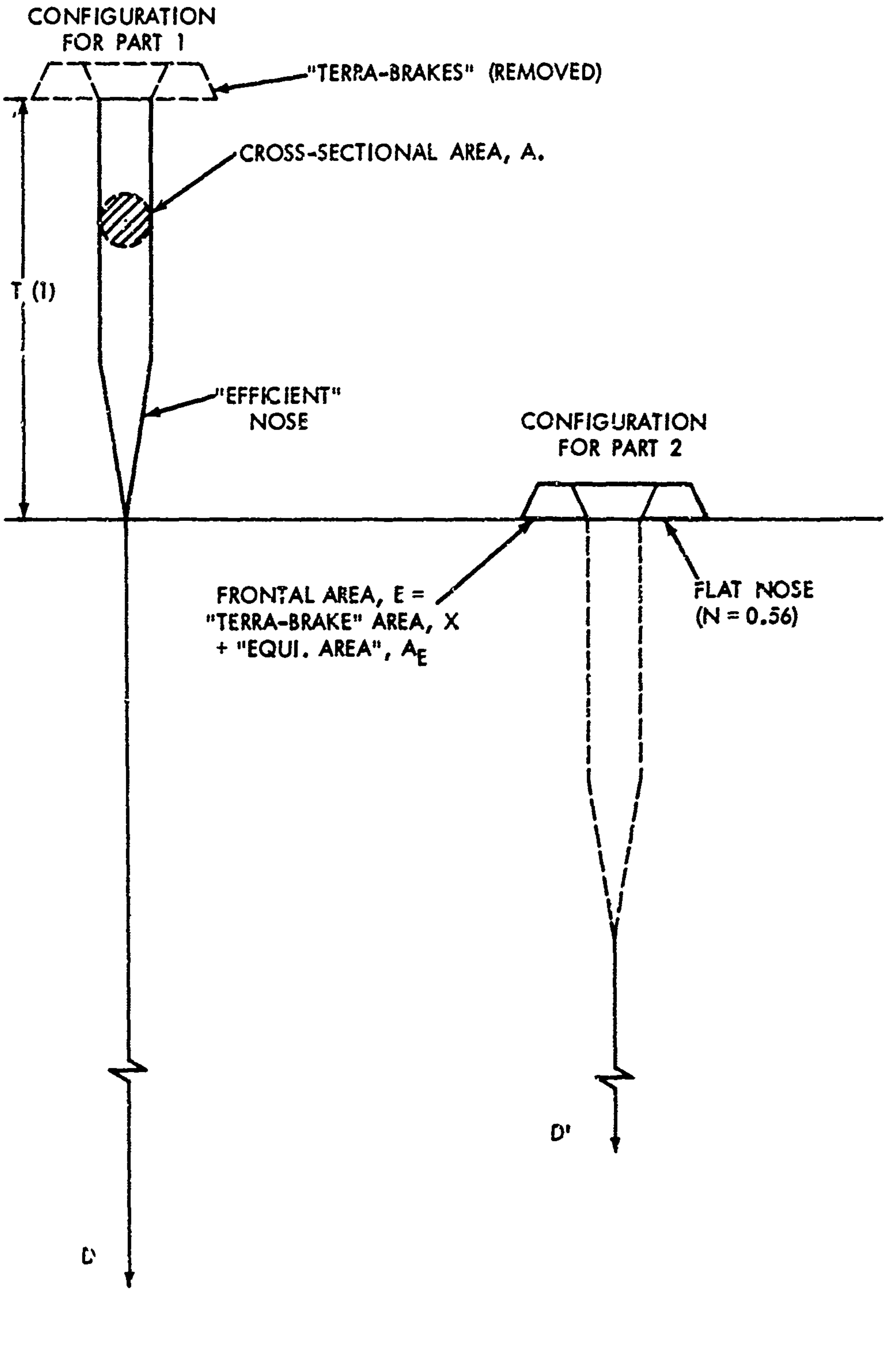


FIG. 3-1 ANALYSIS OF THE PENETRATION OF THE CONTROLLED-PENETRATION VEHICLE INTO A HOMOGENEOUS SOIL.

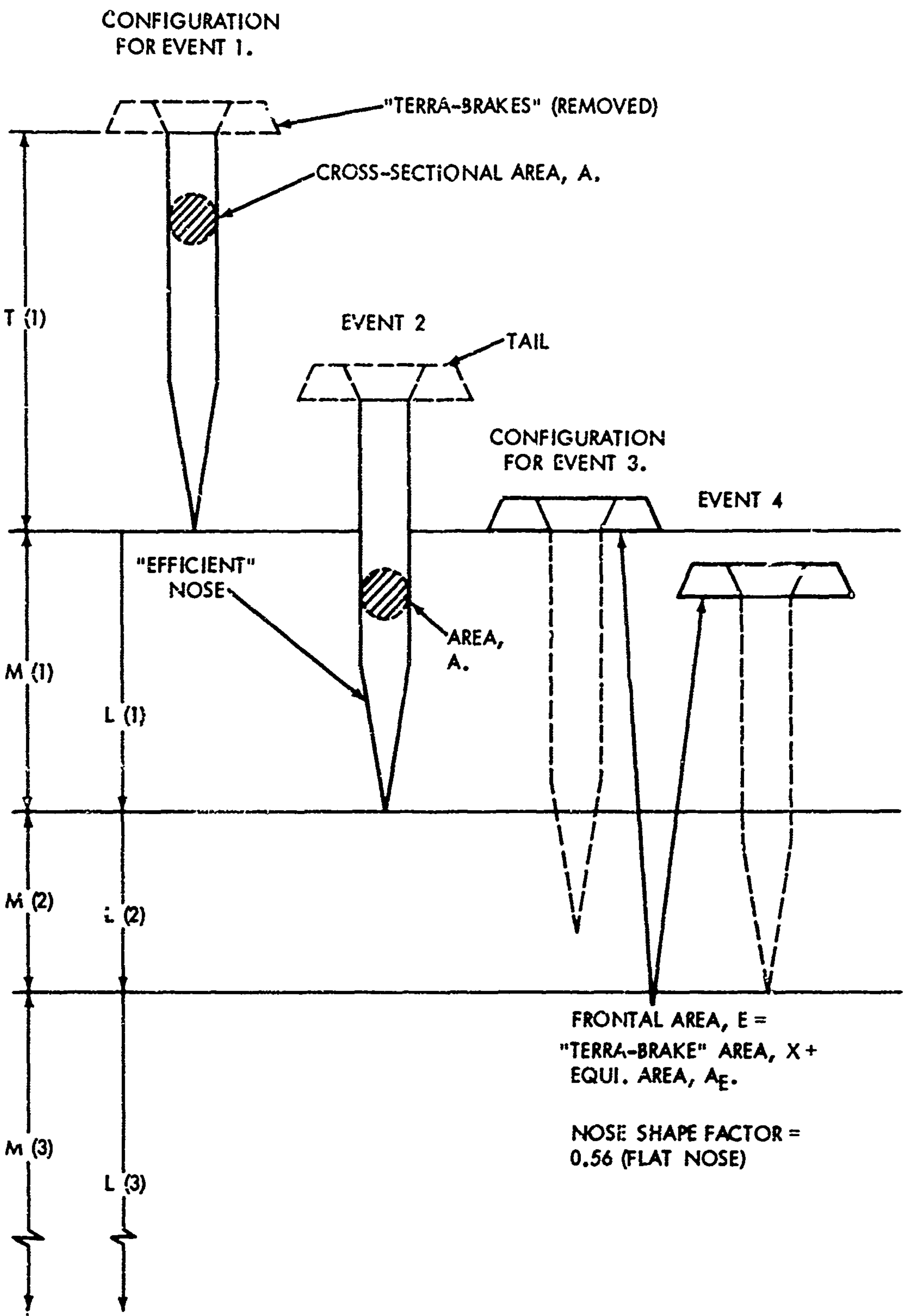


FIG. 3-2 ANALYSIS OF PENETRATION OF THE CONTROLLED-PENETRATION VEHICLE INTO STRATIFORM SOIL.

APPENDIX A

Nose-Performance Coefficients
(Based on 6.0 CRH** Tangent Ogive as 1.0)

Nose Shape	Coefficient
Flat nose	0.56
2.2 CRH tangent Ogive	0.82
6.0 CRH tangent Ogive	1.00
9.25 Tangent Ogive	1.11
12.5 CRH Tangent Ogive	1.22
Cone, l/d* = 2	1.08
Cone, l/d = 3	1.32
Conic step, cone, plus cylinder plus cone	1.28
Biconic, l/d = 3	1.31
Short inverse Ogive, l/d = 2	1.03
Inverse Ogive, l/d = 3	1.32

*l/d is the ratio of the nose length to major diameter.

**Caliber Radius Head

APPENDIX B

Soil Factor, S	Physical Description of Location
2-3	cemented dry lake bed
4-5	ice, glacier
7-9	average sod covered field, clay soil
10-11	sand dunes, moving
25+	first few feet of ooze in a marsh

APPENDIX C

DYNAMIC CONE PENETROMETER READINGS FROM VARIOUS WORLD-WIDE LOCATIONS FOR VARIOUS TYPES OF TOPOLOGY

Data Marked With (*) is Courtesy of:
Mr. Ted Botner
Sandia Corporation/
Defense Communication Planning Group (DCPG)
U. S. Naval Observatory
Washington, D. C.

INDEX

DYNAMIC CONE PENETROMETER (DCP)
BLOW COUNT
(Blows/Ft)

Location and Date	Blow Count Between Indicated Depths In Feet										Remarks
	0'–1'	1'–2'	2'–3'	3'–4'	4'–5'	5'–6'	6'–7'	7'–8'	8'–9'	9'–10'	
Southeast Asia* Nakhon Phanom (NKP), Thailand	6	18	30**					**½	ft.		Dry surface, red clay, rice field
24 Oct 1968	4	8	21								Damp surface, red clay, rice field
	5	13	21								
	5	9	25								Edge of rice field, water 2" deep, rain water
	5	15									
	3	13	24								Rice field, black dirt, 50' from creek, damp
	3	13	22								Rice field, black dirt, 5' from creek, damp
	4	10	12**								Edge of creek bed, 6" of water
	16	27	45								Harvested and pastured dry rice field
	4	17	33**								Partly flooded rice field, red clay appearance
	3	9	26**								

DYNAMIC CONE PENETROMETER (DCP)
BLOW COUNT
(Blows/Ft)

Location and Date	Blow Count Between Indicated Depths In Feet 0'–1'	1'–2'	2'–3'	3'–4'	4'–5'	5'–6'	6'–7'	7'–8'	8'–9'	9'–10'	Remarks
<u>Southeast Asia*</u> (cont'd)	15	27	at 1.5' (hit root)								Taken in jungle on the EOD range, surface was dry and very little humus
	17										
	12 ← hit root										
	15	30	39**					**½ ft.			
	3	4	6								Taken along a creek on the EOD range, sandy soil, looks like basin creek, taken up to 20' from creek
	1	5	14								
	4	6	18								
	8 ← hit root										
<u>Aberdeen Proving Ground, Maryland*</u> "H" Field 28 Sep 1968	33	19	48								No rain for two weeks, hard clay
	18	21	43								
	17	27	49								
	21	23	43								
	22	34	66								
	4	7	9								Swampy area, one inch of water on surface, clay-muddy soil
	4	10	37								
	6	11	12								
	4	12	10								
	4	12	10								
	13	26	26								
	4	6	29								
	9	14	34								

DYNAMIC CONE PENETROMETER (DCP)
BLOW COUNT
(Blows/Ft)

Location and Date	Blow Count Between Indicated Depths In Feet 0'–1'	1'–2'	2'–3'	3'–4'	4'–5'	5'–6'	6'–7'	7'–8'	8'–9'	9'–10'	Remarks
Aberdeen Proving Ground Annex, Md. 13 Feb 1969											
"I" Field: – Zone 8	1		2	4	11	29					Bay Area Marsh, upper foot frozen
– Zone 2		1	9	28							Bay Area Marsh
– Zone 1				1	8	11	26	23			E-Field Marsh, Frozen for first ½ ft.
Firing Position #3	10	13	17	17							4 ft of water on surface of soil
"E" Field – Lego Pt. (Marsh)	1	6	11	24							
– Lego Pt. (Dry)	4	11	29								
	4	11	32								
Ford's Point Marsh (Bay)	.5	1.5	6	13	25						
Defense Communication Planning Group* Washington, D.C. 26 Sep 1968											

DYNAMIC CONE PENETROMETER (DCP)
BLOW COUNT
(Blows/Ft)

Location and Date	Blow Count Between Indicated Depths In Feet: 0'–1'	1'–2'	2'–3'	3'–4'	4'–5'	5'–6	6–7'	7'–8'	8'–9'	9'–10'	Remarks
Defense Communication Planning Group* (cont'd)											
Bldg. 56	36	32	20								No rain for two weeks
	39	10									
	43	27	25								
	54	60	80								
Edgewood Arsenal, Maryland* 4 Oct 1968											
M Field, Manny II	54										Dry soil
	35	33	55								
	24	43	40								
	31	33	28								
	26	33	68								
	28	28	37								
	20	27	9								
Eglin AFB Eglin, Florida											
Range B-70*	11	13	12								
31 March 1969	12	21	15								In grid area, near
	9	13	13								geographical center
	6	7	6								of range
	8	19	15								
	4	11	14								
Range B-75* 1968	6	9	6								No rain for several days,
	7	11	7								sandy soil, open field

DYNAMIC CONE PENETROMETER (DCP)
BLOW COUNT
(Blows/Ft)

Location and Date	Blow Count Between Indicated Depths In Feet										Remarks
	0'–1'	1'–2'	2'–3'	3'–4'	4'–5'	5'–6'	6'–7'	7'–8'	8'–9'	9'–10'	
Range B-75* 1968 (cont'd)	10	13	18								
	7	7	6								
	13	13	6								
	12	11	8								
	8	8	7								
Range B-75* 1968	2	3	7								No rain for several days, tests near tree line for softer soil
	3	4	6								
	3	4	6								
	4	5	7								
	3	5	5								
	7	4	5								
	2.5	2.5	3								
	5.5	5	4								
Range B-75* 3 Feb 1969	1	3	3.5	6							Just outside wooded area
	3	6	4	4							
	2	1.5	3.5	5							In wooded area
	4	6	4.5	3							
	4	4.5	3.5	6							
	.7	1	2.5	4.5							
	1	1	2	3							
	.7	1.3	4	5							
	1.2	1.5	3.2	4							
Range B-75 26 Mar 1969	4	6	5	4	5	8	10	9	13	13	Triangle on N.W. border, near midpoint of base of
	2.5	2.5	3	4	5	8	9	9	13	12	

DYNAMIC CONE PENETROMETER (DCP)
BLOW COUNT
(Blows/Ft)

Location and Date	Blow Count Between Indicated Depths In Feet										Remarks
	0'–1'	1'–2'	2'–3'	3'–4'	4'–5'	5'–6'	6'–7'	7'–8'	8'–9'	9'–10'	
Eglin AFB (cont'd)	6	4.5	3	5	7	7	9	9	11	14	triangle, in open field
	2	3	3	4	5	6	6	7	9	10	area.
Range C-72 25 Mar 1969	2.5	3.5	2.5	2.5	3	5	5	10	17	20	0.3 mi. down range road. open field
	7	9	5	5	4	7	8	12	16	17	0.5 mi. down range road, open field.
Ft. Belvoir, Va. North Area* 9 Oct 1968	40										Clay with small rocks,
	65	102									rain in past week.
	41	42	73								
NASA Wallops Island, Va. 26 Feb 1969											
Extreme North End of Island -low land sand	2	2	6	28	22	32					Sand
	4	5	5	30							Sand
-on beach	3	7	23								Sand, Tidal zone
	3	3	21								Same
Back Bay Side near empty phone poles and road	1	5	9	14	10	5	6	9	9	11	Marsh, very soft underfoot
	1	5	9	9	4	15	8	8	9	10	

DYNAMIC CONE PENETROMETER (DCP)
BLOW COUNT
(Blows/Ft)

Location and Date	Blow Count Between Indicated Depths In Feet: 0'–1'	1'–2'	2'–3'	3'–4'	4'–5'	5'–6'	6'–7'	7'–8'	8'–9'	9'–10'	Remarks
<u>NAVAL ELECTRONIC SYSTEMS TEST & EVALUATION FACILITY</u>											
Webster Field, Md.											
6 Feb 1969											
Primary Drop Area	12	40**					** For ½ ft.				Mowed grass field
	4	36	22	14							
East of Lagoon & N.E.	6	8	45	46	15	32					High grass, thickets
of bldg. 61, field	9	39	16								
	4	10	19	24							
	24	43	60	24							
	14										
Northend of runway 36	8	16	24	13							Mowed grass field
<u>NAVAL ORDNANCE LABORATORY</u>, White Oak, Md.											
5 Feb 1969											
Field behind Admin.	11	25	30	30	25						
Bldg.	16	28	26	33	24						Sod covered field
<u>NAVAL ORDNANCE LABORATORY TEST FACILITY</u>											
Solomons, Md.											
6 Feb 1969											
Drop Field	10	12	16	20	13	15					Sod Stripped Field
	8	9	19	42	32	23					
	8	9	23	56							
	8	5	7	16	17						
	8	11	8	8							

DYNAMIC CONE PENETROMETER (DCP)
BLOW COUNT
(Blows/Ft)

Location and Date	Blow Count Between Indicated Depths In Feet										Remarks
	0'–1'	1'–2'	2'–3'	3'–4'	4'–5'	5'–6'	6'–7'	7'–8'	8'–9'	9'–10'	
NAVAL ORDNANCE LABORATORY TEST FACILITY (cont'd)											
Drop Field											
Location of ADST-4	4	4	5	7	7	10	16	24	33	42	5 Mar 69
-4	4	11	4	11							7 Mar 69 (snow & rain)
Location of ADST-5	17	21	22	22	15	20	30	39	36		5 Mar 69
-5	11	25	15	23							7 Mar 69 (snow & rain)
Location of ADST-6	15	5	8	11	16	20	27	45	26	28	5 Mar 69
-6	9	7	13	7	10	14	30	40			12 Mar 69
Location of ADST-7	6	7	12	20	11	10	18	26	28	36	5 Mar 69
-7	6	10	18	19	15	16	19	24			12 Mar 69
Extra Test On Field	10	13	17	18	13	17	20	21	24	24	12 Mar 69
U. S. NAVAL FACILITY Lewes, Delaware 25 Feb 1969											
S.E. Corner of Facility											
-at fence	3	10	16	10	6	8	26	9.5	11	10	Sand, Loose
-waterline	1.5	6.5	10	7	14	12.5	6	16			Sand, Tidal Area
-on dune	2	4	8	10.5	15	10	4	5	20	8	Sand, Loose
Half-way between Bldg. 2 & the waterline											
-on dune	2	7	5	8	33	45					Sand, Loose
-in hollow	3	16	14	7	5	3	6	4	5.5	2	Same
-on dune	1.5	5.5	5	6	10	6	11	21			Same
-off dunes	3	8	8	6	8	9	5	3	18	33	Sand
	1	4	7	15	17	26	19	17			Sand

DYNAMIC CONE PENETROMETER (DCP)
BLOW COUNT
(Blows/Ft)

Location and Date	Blow Count Between Indicated Depths In Feet: 0'–1'	1'–2'	2'–3'	3'–4'	4'–5'	5'–6'	6'–7'	7'–8'	8'–9'	9'–10'	Remarks
Scaline Dune Opposite Bldg. 2	2	8	16	32							Sand
Pine Woods, Middle Finger	1	5	10	12	8	12	15	3	8	12	Needles on the ground
<u>U. S. NAVY EOD FACILITY</u> Stumpneck, Md. 11 Feb 1969											
Observation Point		1		4	5	9					Marsh 200' E. of bldg.
		1	9	10	15	25					Marsh, 300' north of
		1	11	11	15	38					Same bldg.
Causeway Area			1			7					Marsh area on land side of road

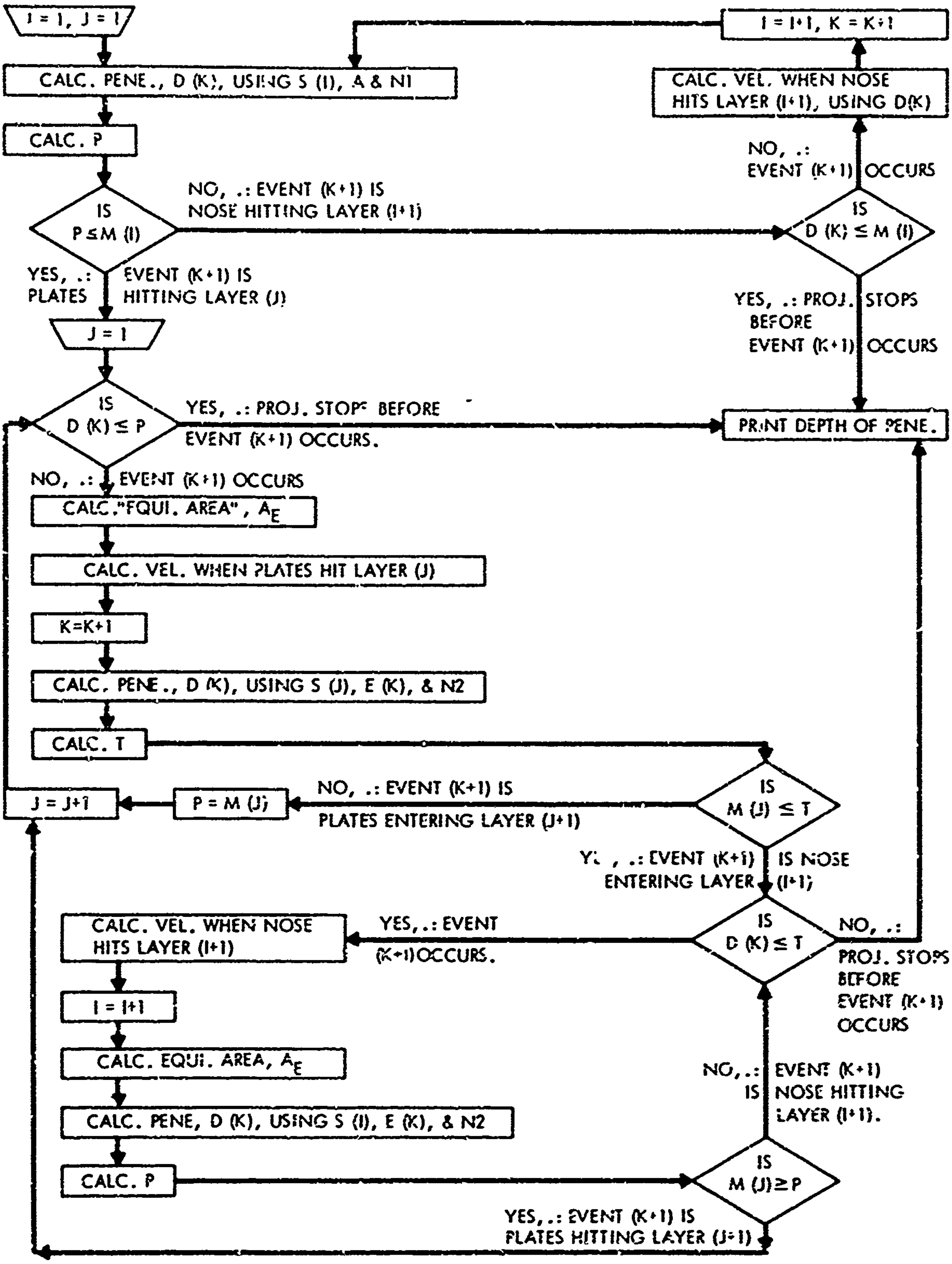
APPENDIX D

LIST OF PARAMETERS FOR COMPUTER PROGRAM H7H 438

A	CROSS-SECTIONAL AREA OF PROJECTILE. (IN^2)
B	LENGTH OF "TERRA-BRAKES". (FT)
D	DIAMETER OF PROJECTILE. (IN)
D(K)	PENETRATION OF PROJECTILE AT EVENT K. (FT)
E(K)	"TERRA-BRAKE" AREA, ADDED TO "EQUIVALENT AREA" AT EVENT K. (IN^2)
L(I)	DISTANCE FROM SURFACE TO LAYER I + 1. (FT)
M(I)	THICKNESS OF LAYER I. (FT)
N1	NOSE SHAPE FACTOR FOR AN "EFFICIENT" NOSE. (1.32 FOR 3 TO 1 CONICAL NOSE)
N2	NOSE SHAPE FACTOR FOR A FLAT NOSE. (0.56)
P	DISTANCE FROM "TERRA-BRAKES" TO THE NEXT LAYER THEY WILL ENCOUNTER. (FT)
R	DEPTH OF PENETRATION OF PROJECTILE. (FT)
S(I)	SOIL FACTOR FOR LAYER I.
T	DISTANCE FROM NOSE TO THE NEXT LAYER IT WILL ENCOUNTER. (FT)
T(I)	LENGTH OF PROJECTILE, MEASURED TO "TERRA-BRAKES". (FT)
V(I)	IMPACT VELOCITY OF NOSE. (FT/SEC)
V(K)	VELOCITY OF PROJECTILE AT EVENT K. (FT/SEC)
W	WEIGHT OF PROJECTILE. (LBS)
X	SURFACE AREA OF "TERRA-BRAKES". (IN^2)
Y	DEPTH OF PENETRATION OF PROJECTILE. (FT)
Z	NUMBER OF LAYERS.

ABBREVIATIONS

$\therefore$	— THEREFORE
CALC	— CALCULATE
EQUI	— EQUIVALENT
PENE	— PENETRATION
PROJ	— PROJECTILE
VEL	— VELOCITY



I - INDEX INDICATING LAYER THAT NOSE IS TRAVELING IN
J - INDEX INDICATING LAYER THAT "TERRA-BRAKES" ARE TRAVELING IN
K - INDEX INDICATING EVENT NUMBER

FLOW CHART FOR COMPUTER PROGRAM H7H438

COMPUTER PROGRAM H7H 438

```
100 DIM S(99),M(99),L(99),D(99),V(99),E(99)
110 LET L(0)=0
120 READ Z
130 FOR I= 1 TO Z
140 READ S(I),M(I)
150 LET L(I)=L(I-1)+M(I)
160 NEXT I
170 READ W1,D,X,T(1),J,S,V(1)
180 LET A=3.14*D↑2/4
190 LET E=0
200 LET Y=0
210 LET I=1
220 LET K=1
230 LET P=T(1)-Y
240 IF V(K)<200 THEN 280
250 LET D(K)=.0031*S(I)*W1*(W/A)↑.5*(V(K)-100)
260
270 GOTO 290
280 LET D(K)=.53*S(I)*W1*(W/A)↑.5*LOG(1+.00002*V(K)↑2)
290 IF P<=M(I) THEN 360
300 IF D(K)<=M(I) THEN 700
310 LET Y=L(I)
320 LET V(K+1)=V(K)*(1-M(I)/D(K))↑.5
330 LET K=K+1
340 LET I=I+1
350 GOTO 230
360 LET J=1
370 IF D(K)<=P THEN 700
380 LET Y=Y+P
390 LET T=L(I)-Y
400 LET E(K+1)=A*(S(J)*.56/(S(I)*W1))↑2*X
410 LET V(K+1)=V(K)*(1-P/D(K))↑.5
420 LET K=K+1
430 LET E=E+1
440 IF E>1 THEN 460
450 LET Q=V(K)
460 IF V(K)<200 THEN 490
470 LET D(K)=.0031*S(J)*.56*(W/E(K))↑.5*(V(K)-100)
480 GOTO 500
490 LET D(K)=.53*S(J)*.56*(W/E(K))↑.5*LOG(1+.00002*V(K)↑2)
500 IF M(J)>=T THEN 550
510
520 LET P=M(J)
530 LET J=J+1
540 GOTO 370
550 IF D(K)<=T THEN 700
560 LET V(K+1)=V(K)*(1-T/D(K))↑.5
570 LET Y=L(I)
580 LET I=I+1
590 LET K=K+1
600 LET E(K)=A*(S(J)*.56/(S(I)*W1))↑2*X
610 IF V(K)<200 THEN 640
620 LET D(K)=.0031*S(J)*.56*(W/E(K))↑.5*(V(K)-100)
630 GOTO 660
640 LET D(K)=.53*S(J)*.56*(W/E(K))↑.5*LOG (1+.00002*V(K)↑2)
650
660 LET P=L(J)+T(1)-Y
670 IF M(I)>=P THEN 500
680 LET T=M(I)
690 GOTO 550
700 PRINT "IMPACT VEL. OF NOSE (FT/SEC)="V(1)
710 PRINT "IMPACT VEL. OF TERRA-BRAKES (FT/SEC)="Q
720 PRINT
730 PRINT "LAYER NO.","SOIL FACTOR","THICKNESS (FT)"
740 PRINT "---------","-----------","--------------"
750 FOR I=1 TO Z
760 PRINT I,S(I),M(I)
770 NEXT I
780 PRINT
790 LET R=0
800 LET I=1
810 IF V(I)<200 THEN 840
820 LET D(I)=.0031*S(I)*W1*(W/A)↑.5*(V(I)-100)
830 GOTO 850
840 LET D(I)=.53*S(I)*W1*(W/A)↑.5*LOG(1+.00002*V(I)↑2)
850 IF D(I)<=M(I) THEN 900
860 LET R=R+M(I)
870 LET V(I+1)=V(I)*(1-M(I)/D(I))↑.5
880 LET I=I+1
890 GOTO 810
900 PRINT "PENE. TO TAIL, WITH TERRA-BRAKES (FT)="Y+D(K)-T(1)-8
910 PRINT "PENE. TO TAIL, W/O TERRA-BRAKES (FT)="R+D(I)-T(1)-8
920 DATA 2,7.5,4,6.5,170
930 DATA 1.32,10.843,475,4.155,.3415
940 DATA 772
950 DATA 350
960 END
```

REFERENCES

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Security Classification

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4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

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13. ABSTRACT

Within the scope of the work conducted in the discipline of controlled penetration in soils, techniques are outlined and suggested which should help the investigator estimate the resistance to penetration (soil factor) at a location in a few minutes using portable equipment. Included is a compilation of soil penetration data from various locations. Additional work has also been completed which enables the researcher to theoretically predict burial depths of impacting vehicles in stratiform soil or earth.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Penetration						
Soil						
Burial						
Advanced Destructor						

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There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

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